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INTRODUCTION

Stream sediment geochemistry and heavy mineral surveys are routinely used in the early stages of gold exploration in the Cordillera. However, it is well known that results of such surveys are often extremely erratic and difficult to reproduce or confirm. Such problems are typical of geochemical patterns for elements that are principally transported in stream sediments as the constituents of rare grains of heavy minerals (Fletcher and Day, 1988a, b).

In part, as discussed by Clifton *et al.* (1969), the erratic response arises from the problems inherent in obtaining samples that are statistically representative of the true abundance of rare particles. However, even when care is taken to obtain representative samples, the geochemical patterns remain erratic and difficult to follow-up. In large measure this is a result of hydraulic processes that preferentially sort and deposit heavy minerals during sediment transport. Under the most favorable conditions, these processes can lead to development of heavy mineral placers. However, in exploration geochemical surveys the localized and ephemeral nature of heavy mineral enrichments on the stream bed can become a source of considerable noise.

Despite its relevance to both origins of placer deposits and design and interpretation of exploration geochemical surveys, little has been published on the sedimentological behaviour of gold particles in streams. Therefore, starting in 1985, as part of a broader study of heavy minerals in streams, distribution and transport of free gold have been investigated in streams in southern British Columbia. These investigations initially had two objectives:

- To establish the size distribution of gold as a basis for recommendations on the optimum size fraction and amount of sample required to obtain reliable results; and,
- To study any systematic variations in the distribution of gold among stream bedforms or along a stream's longitudinal profile as a basis for recommendations on optimum sites for sample collection.

In addition, by obtaining a more fundamental understanding of the relationships between sediment transport and distribution of gold, it was hoped to identify and then investigate other factors that might be relevant to design and interpretation of stream sediment and heavy mineral surveys for gold. For example, only during the course of the study did it become apparent that changing discharge conditions and their effect on seasonal variations in gold concentrations were likely to be of considerable practical significance.

Many aspects of these investigations have already been published (Day, 1987; Day and Fletcher, 1986, 1989; Fletcher and Day, 1988a; 1988b; 1989; Fletcher and Horsky, 1988; Fletcher and Wolcott, 1989; and Fletcher and Zhang, 1989). The purpose of this report is to summarize and bring these findings together in a convenient form that emphasizes their practical implications for use of stream sediment surveys in gold exploration. The report is divided into three main sections: (i) size distribution of gold in sediments; (ii) distribution among bedforms and along the longitudinal profile; and (iii) seasonal variations in gold concentrations.

SIZE DISTRIBUTION OF GOLD IN SEDIMENTS

INTRODUCTION

Clifton *et al.* (1969) thoroughly discuss the problems associated with obtaining samples that will be representative of gold concentrations when it is present as rare particles of free gold. They showed, based on the binomial distribution, that it is necessary to have, on average, at least twenty particles of gold to obtain a relative sampling error (with 95% confidence limits) of approximately ±50 per cent. A similar result can be predicted, more simply, from the Poisson distribution where relative error (RE%) is approximated by:

$$RE(\%) = \pm 200\sqrt{n}$$

when **n** is the average number of gold particles in a sample of a given size. Furthermore, as the number of particles of gold decreases below twenty the probability of no particles (P_0) of gold being found increases. For example, with **n** = 1 or 0.1, the probabilities of finding no free gold in a single sample are 37 per cent and 90 per cent, respectively. For practical purposes this corresponds to the probability of missing an anomaly. Conversely, the sporadic presence of one or more gold particles in small samples will give very strong, nonreproducible anomalies. Harris (1982) gives some field examples of these situations.

From the foregoing it would seem that, where reliability of a single sample might be important to the outcome of an entire survey (as is most likely to be the case with low density, reconnaissance surveys), the analyzed portion of an anomalous sample should ideally contain at least twenty particles of gold. This, however, assumes that all gold particles are the same size - a most unlikely event in most natural samples. Under these circumstances, because a single large particle of gold will contribute considerably more to the total gold content than many small particles, a conservative estimate of the required sample size should be based on the average number of the larger particles of gold present.

A further aspect of the problem is the need to concentrate free gold from a bulk sample into a much smaller heavy mineral concentrate that is both representative and small enough to be analyzed by conventional methods. Unfortunately this is both costly and can result in significant losses of fine gold (Wang and Poling, 1983; Giusti, 1986).

Clearly, a starting point for evaluating sampling requirements are data on the size and abundance of gold particles in stream sediments. No such published data exist for British Columbia. The objective of this phase of the study was therefore to obtain the necessary information. Results are published in greater detail in Day (1987), Day and Fletcher (1986) and Fletcher and Zhang (1989).

METHODOLOGY

Bulk sediment samples were collected from high and low-energy environments, usually at bar-heads and bar-tails, respectively, in the vicinity of known gold mineralization at the locations shown in Figures 1 and 2.

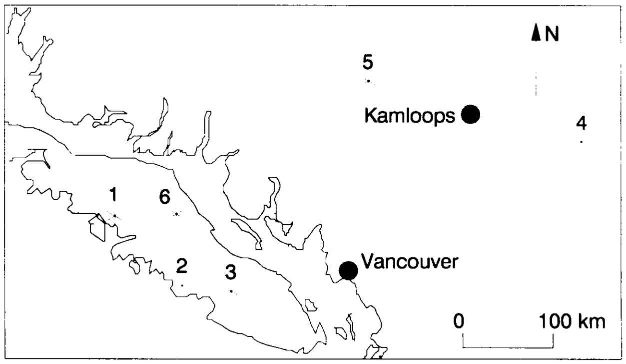

Figure 1. Sampling locations: 1 = Tsowwin River; 2 = Salmonberry Creek; 3 = Franklin River; 4 = Harris Creek; 5 = Watson Bar; 6 = Mount Washington. See Figure 2 for details of Mount Washington locations.

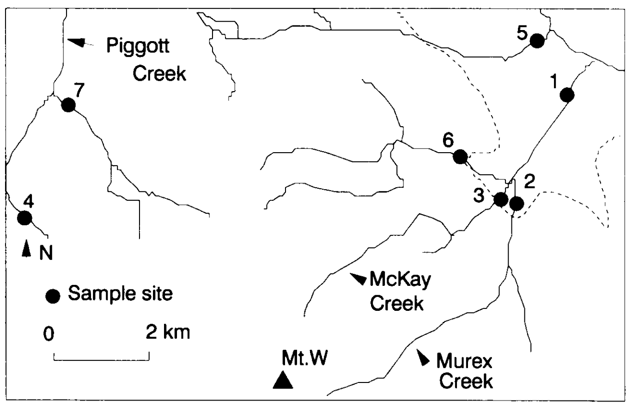

Figure 2. Sampling locations at Mount Washington, Mt.W = Mount Washington, dashed line is western limit of complex drift. Based on Fletcher and Zhang, 1989.

With the exception of the Mount Washington streams, each sample consisted of 20 kilograms (wet weight) of -5 millimetre (4 mesh) material obtained by wet sieving at the sample site. Based on initial results, sample size at Mount Washington was increased to 50 kilograms of -2 millimetre (10 mesh) sediment. In high-energy environments, where the stream bed is usually a cobble-gravel pavement, collection of this much sediment typically requires on-site processing of up to 250 kilograms of bed material. Considerably less material must be processed at sandy, low-energy bar-tail sites and sampling time is correspondingly shorter.

In the laboratory, samples were wet sieved into seven size fractions from -270 to -4 mesh (all mesh sizes quoted are ASTM). Heavy mineral concentrates were then prepared for the five fractions between 270 and 50 mesh using methylene iodide (SG = 3.3). Gold content of each fraction was determined by either instrumental neutron activation analysis (locations 1 to 5, Figure 1) or fire assay - atomic absorption (Mount Washington).

RESULTS AND DISCUSSION

In all cases the light mineral fractions (SG<3.3) contained concentrations of gold close to or below analytical detection limits - typically less than 10 ppb. Table 1 therefore only summarizes results for the -270 mesh and heavy mineral fractions. These data, together with the weights of the heavy mineral fractions have been used to calculate the absolute amount of gold in each sample and then estimate the number of particles of free gold likely to be present (Table 2). These estimates assume the gold had a density of 15 grams per cubic centimetre and is present as spheres with a diameter equal to the geometric mean of the bounding sieve openings. For the -270 mesh fraction a diameter of 20 microns was assumed. An alternative assumption, of flakes of gold with a diameter to thickness ratio of 10:1, would increase estimates of the number of particles two or three times.

It is apparent from Table 2 that, except for Harris Creek and Murex and McKay creeks on Mount Washington, the total number of particles of free gold estimated to be in the heavy mineral concentrates seldom approaches the recommended value of twenty. Indeed, only two out of twenty-eight concentrates coarser than 100 mesh are estimated to contain free gold. This would increase to eleven out of twenty-eight cases if flakes rather than spheres of gold were assumed. In the remaining concentrates gold is presumably present as inclusions. In contrast to the heavy mineral concentrates, a 30 gram subsample of the -270 mesh fraction is much more likely to contain an adequate number of gold particles. This is

TABLE 1. GOLD ANALYSES OF HEAVY MINERAL CONCENTRATES AND -270 MESH SEDIMENT. ALL VALUES IN PPB. BASED ON DAY AND FLETCHER (1986), AND FLETCHER AND ZHANG (1989).

Stream	Site	Mesh (ASTM) -50 +70	-70 +100	-100 +140	-140 +200	-200 +270	-270
Tsowwin	L	3200	4000	6200	53	6000	nd
	H	nd	35	5300	23000	150	34
	B	nd	11	13	6000	2100	nd
Salmon-berry	L	16	31	3400	237	3300	15
	H	3400	3700	35	480	2800	15
	B	350	190	8400	19000	2300	34
Franklin	L	870	4100	12000	6900	10000	110
	H	280	540	520	22000	500	59
Harris	L	455	1130	890	3250	3100	320
	H	750	1480	720	1200	1600	89
	B	730	590	3000	7400	3600	nd
Watson Bar	L	160	3000	13000	940	7800	27
	H	nd	200	nd	2900	6000	50
	B	11	250	1000	23	130	21
Mount Washington (Figure 2 for locations)							
McKay 1	H	-	800	3215	2745	1640	330
McKay 3	H	-	6755	15505	19330	14440	1000
McKay 6	H	-	4135	6665	nd	nd	200
Murex 2	H	-	10440	10225	8730	15000	910
Tsolum 5	H	-	5	705	25	nd	50
Piggott 4	H	-	6700	4455	1545	2035	50
Piggott 7	H	-	155	3825	nd	1540	60

L = low energy; H = high energy; B = background; nd = not detected

TABLE 2. ESTIMATED NUMBER OF PARTICLES OF FREE GOLD IN HEAVY MINERAL CONCENTRATES AND -270 MESH FRACTION. BASED ON DAY AND FLETCHER (1986), AND FLETCHER AND ZHANG (1989).

Stream	Site	Mesh (ASTM) -50 +70	-70 +100	-100 +140	-140 +200	-200 +270	-270[1]
Tsowwin	L	.5	1.0	2.4	.0	5.7	.0
	H	.0	.0	.3	1.2	.0	16.2
	B	.0	.0	.0	.9	.7	.0
Salmon-berry	L	.0	.0	.9	.0	.8	7.1
	H	.4	.5	.0	.7	.5	7.1
	B	.0	.0	.7	1.9	.5	16.2
Franklin	L	.2	.9	3.9	3.0	2.8	52.4
	H	.0	.0	.0	.8	.0	28.1
Harris	L	.8	6.5	12.7	40.9	53.6	152
	H	.7	2.6	1.9	2.3	2.6	42.4
	B	.7	1.6	11.8	16.7	10.1	.0
Watson Bar	L	.0	.6	4.5	.4	6.5	12.9
	H	.0	.0	.0	.6	2.2	23.8
	B	.0	.0	.2	.0	.0	10.0
Mount Washington (Figure 2 for locations)							
McKay 1	H	-	.9	4.3	6.7	4.0	158
McKay 3	H	-	4.7	12.5	14.8	14.0	478
McKay 6	H	-	.8	1.5	.0	.1	200
Murex 2	H	-	4.2	5.8	9.8	8.9	435
Tsolum 5	H	-	.0	.5	.0	.1	23.9
Piggott 4	H	-	3.6	6.8	3.0	6.9	23.9
Piggott 7	H	-	.1	2.2	.0	1.1	28.7

L = low energy; H = high energy; B = background
1 = Estimated number of gold particles in a 30 g subsample

particularly true for sediments from McKay and Murex creeks.

Based on these results, use of heavy mineral concentrates would be expected to give, as in Table 1, extremely erratic results and might even fail to detect the presence of an anomaly. However, if heavy mineral concentrates are to be used, it is obvious that size fractions finer than 100 or 140 mesh are most likely to contain significant numbers of particles of free gold and give the most reproducible results. In Table 3 the relationships between size distribution of gold and sediment are re-expressed as estimates of the amount of field sample required to give twenty particles of gold in either -100+270 mesh heavy mineral concentrates or the -270 mesh fraction.

Data in Table 1 suggest that low-energy sites have similar or even higher gold concentrations than high-energy sites. This result, which leads to estimates that smaller field samples are required from low energy sites

TABLE 3. FIELD SAMPLE SIZE (KG) REQUIRED TO OBTAIN 20 PARTICLES OF FREE GOLD IN -100+270 MESH HEAVY MINERAL CONCENTRATES AND THE -270 MESH FRACTION. BASED ON DAY (1987) AND FLETCHER AND ZHANG (1989).

Stream	Site	HMC		-270 mesh	
		-4 mesh	-16 mesh	-4 mesh	-16 mesh
Tsowwin	L	50.9	18.7	ne	ne
	H	263.0	37.0	23.3	3.3
	B	227.9	30.8	ne	ne
Salmon-berry	L	243.1	71.8	57.2	16.9
	H	ne	ne	52.5	10.5
	B	118.7	35.1	22.5	6.6
Franklin	L	44.1	23.8	8.2	4.4
	H	ne	ne	11.6	3.1
Harris	L	4.4	3.8	3.1	2.6
	H	83.1	46.5	13.3	7.5
	B	14.3	6.6	ne	ne
Watson Bar	L	45.4	20.0	40.0	17.6
	H	152.9	70.7	18.0	8.3
	B	ne	ne	62.6	36.2
Mount Washington (Figure 2 for locations)					
		-10 mesh		-10 mesh	
McKay 1	H	64.7		0.37	
McKay 3	H	24.2		0.21	
McKay 6	H	344.7		0.55	
Murex 2	H	37.7		0.21	
Tsolum 5	H	ne		7.3	
Piggott 4	H	56.0		1.0	
Piggott 7	H	190.0		1.5	

L = low energy; H = high energy; B = background
ne = no estimate because of too few particles

(Table 3), is initially surprising because, as is well known to both prospectors and in published data (*e.g.*, Saxby and Fletcher, 1987; Fletcher *et al.*, 1987), heavy minerals tend to accumulate in high-energy environments. However, the bulk of the -5 millimetre fraction at these sites is coarser than 140 mesh, whereas sediment finer than 140 mesh is two to three times more abundant at low-energy sites (Table 4). A larger field sample is thus required to obtain the same amount of fine sediment at high-energy sites. In this study, with the field sample fixed at 20 kilograms of -5 millimetre sediment, a smaller heavy mineral concentrate is available from high-energy sites. An important consequence of this is that, with so few particles of gold present, the Poisson distribution leads to underestimation of true gold values. If samples of sufficient size are collected it becomes apparent that, as described in the next section, gold is actually enriched at high energy sites.

Results in Table 3 also show that use of the -270 fraction should require a much smaller field sample than preparation of a heavy mineral concentrate. Furthermore, in many cases a 30 gram subsample (*i.e.*, roughly an assay ton and a practical upper limit for fire assay) of -270 mesh material is sufficient to provide twenty particles of gold (Table 2). This is of practical significance insofar as it suggests that the need for (expensive) preparation of a heavy mineral concentrate can be avoided by direct analysis of the -270 mesh fraction (or of a coarser size fraction provided the bulk of it consists of -270 mesh sediment). Where a 30 gram analytical subsample is inadequate, a larger sample could be analyzed by cyanidation as described by Fletcher and Horsky (1988).

TABLE 4. WEIGHT PER CENT SEDIMENT SIZE FRACTIONS. BASED ON DAY (1987).

Site		Mesh (ASTM)					
		-4 +16	-16 +50	-50 +70	-70 +140	-140 +270	-270
Tsowwin	L	63.3	32.2	1.81	1.40	.51	.75
	H	85.9	12.6	.56	.40	.28	.22
	B	86.5	11.8	.58	.50	.22	.40
Salmon-berry	L	70.5	26.7	1.55	.84	.21	.22
	H	80.0	18.5	.82	.48	.12	.17
	B	70.4	25.6	1.85	1.28	.35	.45
Franklin	L	46.0	47.7	3.01	2.03	.49	.80
	H	73.1	25.2	.84	.49	.15	.30
Harris	L	14.9	66.4	8.72	7.28	1.49	1.24
	H	44.0	49.3	3.55	2.36	.44	.34
	B	53.6	36.6	3.60	3.19	.89	2.12
Watson Bar	L	56.0	35.3	3.68	2.98	.87	1.20
	H	53.8	38.9	3.08	2.41	.79	1.11
	B	42.2	44.7	9.01	3.10	.84	.17

L = low energy; H = high energy; B = background

DISTRIBUTION OF GOLD AMONG BEDFORMS AND ALONG THE LONGITUDINAL PROFILE

INTRODUCTION

On the basis of its exceptional gold content and relatively large number of particles of free gold (Tables 1 and 2), Harris Creek was chosen for detailed studies of systematic variation in distribution of gold on the stream bed. Results obtained and their implications for exploration are considered in greater detail by Day (1988), Day and Fletcher (1989, 1990) and Fletcher and Day (1988b, 1989). Before describing these investigations and considering their implication to exploration, it is useful to review some theoretical aspects of drainage surveys and transport of heavy minerals by streams.

THEORY

Widespread acceptance of sediments as a sample medium in exploration surveys is based on the premise that sediment composition is representative of the geochemistry of the catchment basin upstream of the sample site. In the guidelines for such surveys it is usually specified that active sediments (*i.e.*, sediments in the process of being transported by the stream) should be sampled (Levinson, 1974). If an anomaly is followed upstream, the point of maximum metal values is known as the cut-off. This is usually considered to be close to the source of the anomaly and thus the starting point for follow-up.

As a guide to design and interpretation of sediment surveys, Hawkes (1976) described an anomaly dilution model:

$$Me_mA_m = A_a(Me_a-Me_b) + A_mMe_b$$

where:

Me_m is the metal content of the anomaly source;

Me_a is the metal content of an anomalous sediment;

Me_b is the metal content of a background sediment;

A_m is the area of the anomaly source;

A_a is the area of the catchment upstream of the anomalous sample site.

This model, which generates a smooth exponential decay curve for the anomalous dispersion train downstream from the cut-off point, is based on several assumptions: uniform rate of erosion; uniform geochemical background; no feedback between water and sediment; no sampling error; a single anomalous source; and no contamination. A further implicit, but generally unstated assumption, is that, within any one size fraction, the various components of the sediments are transported at the same rate and without segregation. Placer deposits indicate that this need not be the case for heavy minerals.

From the foregoing, it is apparent that the sedimentological behaviour of gold is relevant to the design and interpretation of stream sediment and heavy mineral surveys for gold. Most of the literature on this topic relates to origins of heavy mineral placers. Slingerland (1984) classifies and gives examples of heavy mineral placers at the bed (10^0 m), bar (10^2 m) and system (10^4 m) scales. Heavy mineral placers at the bed and bar scale are sources of local sampling variability in geochemical surveys. The system scale relates to trends in heavy mineral distribution along a stream's longitudinal profile and hence to the interpretation of Hawke's dilution-curve model. Insofar as system-scale variations are partly a cumulative response to bed and bar-scale processes acting along the longitudinal profile in conjunction with changes in stream gradient and discharge, it is useful to consider the local processes first.

Selective accumulation of particles of free gold on the bed of a stream occurs if their motion stops (deposition) or starts (erosion) under different conditions to that of the rest of the sediment. The processes involved are referred to as settling and entrainment, respectively. Thus mineral grains that, despite differences in their physical properties, accumulate together on the stream bed exhibit either settling or entrainment equivalence depending on the process involved. Settling equivalence is also sometimes known as hydraulic equivalence (Rubey, 1933; Rittenhouse, 1943).

The role of these sorting processes in development of stream placers is discussed by Grigg and Rathbun (1969), Slingerland (1984), Slingerland and Smith (1986), and Reid and Frostick (1985). Settling sorting involves the relative settling velocity of mineral grains (predicted by Stokes' Law for spheres <0.5 mm diameter) as determined by their size, shape and density. It results in small particles of high density being deposited together with larger, less dense mineral grains. Conversely, if size or shape results in the heavy minerals having lower settling velocities than the bulk of the sediment being transported, they will be carried higher in the stream flow and may become concentrated in overbank deposits on the flood plain (Slingerland, 1984). This might be particularly relevant to behaviour of fine flakes of "skim" gold.

Entrainment sorting is closely related to Shields' criterion for the onset of transport of grains in response to the shear stresses acting on them (Grigg and Rathbun, 1969). As would be expected, denser grains are less easily entrained than less dense grains of the same size and can therefore remain on the bed as a lag deposit. However, this simple concept of entrainment is only valid for stream beds consisting of uniformly sized grains. With reasonably well-sorted sands it is likely that larger grains protruding further into the flow will be entrained more easily than the bed as a whole (Slingerland and Smith, 1986; Reid and Frostick, 1985). Entrainment should thus sort for size as well as density and tends to narrow the size difference between light and heavy minerals that remain in the bed. It is an important process in the development of heavy mineral strand lines along the swash zone of beaches.

The shielding (or hiding) effect whereby large clasts protect small particles from the turbulent stream flow, is not considered in simple entrainment models. Behaviour of heavy minerals is therefore probably better predicted by more sophisticated transport models that consider: (i) size and density of the mineral grains; (ii) bed characteristics - particularly roughness and ability to shield particles from full turbulent flow; and, (iii) hydraulic conditions - channel width, depth, slope, flow velocity, discharge and loss of energy by friction against the bed and banks.

Many bedload transport formulae have been proposed. Probably none are capable of accurate prediction of sediment transport rates in real streams (Gomez and Church, 1989). They do, however, provide a basis for studying the effect of varying conditions on relative transport rates of low and high-density minerals. Slingerland (1984), Fletcher and Day (1988b, 1989) and Day and Fletcher (1990) have used the bedload transport formula of Einstein (1950) for this purpose. The following discussion largely follows Day and Fletcher (1990).

Estimated rates of transport for quartz (density = 2.7 g/cm^{-3}), magnetite (density = 5.2 g/cm^{-3}) and gold (density = 18 g/cm^{-3}) grains moving over a cobble bed with empty voids are shown in Figure 3. It is apparent that grains close to the median diameter of the bed have the highest transport rates whereas transport rates for very fine particles are several orders of magnitude lower. In Figure 4 curves similar to those of Figure 3 have been ratioed to obtain log transport ratios of quartz:magnetite and quartz:gold for different bed roughness conditions. The higher the ratio, the greater the chance of quartz

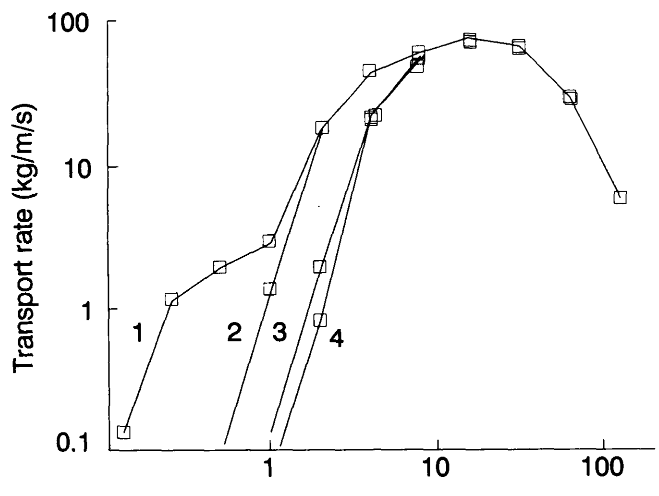

Figure 3. Transport rates for quartz and magnetite over a gravel bed calculated using Einstein's bedload function. Curves (1) and (3) for quartz moving over gravel beds with characteristic roughness (D_{65}) of 4 and 8 mm, respectively. Curves (2) and (4) are the corresponding plots for magnetite. All curves computed with a stream velocity of 1.0 ms^{-1}, wetted perimeter 6.1 m and stream discharge of 1.83 m^{3}s^{-1}. D35 for the bed = 1.0 mm. From Day and Fletcher (1990).

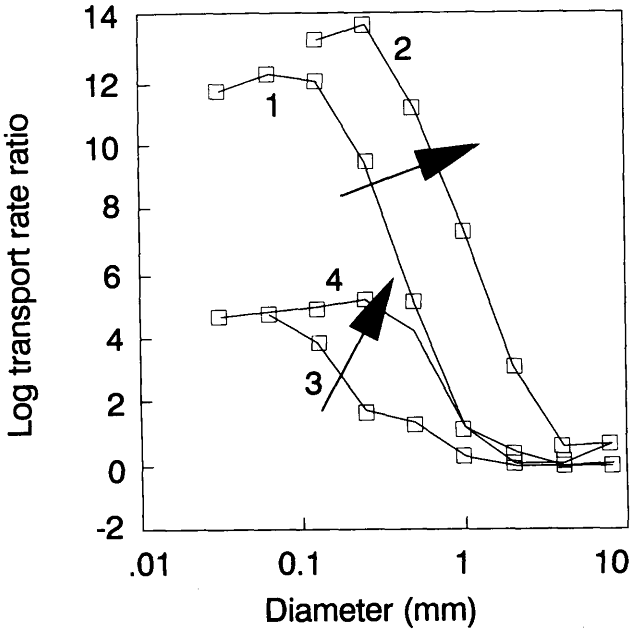

Figure 4. Transport rate ratios for quartz:magnetite and quartz:gold calculated using Einstein's bedload function. Curves (1) and (2) for gold with characteristic bed roughness (D_{65}) of 4.0 and 8.0 mm, respectively. Curves (3) and (4) are the corresponding plots for magnetite. Arrows indicate direction of increasing bed roughness. General hydraulic conditions as in Figure 3. From Day and Fletcher (1990).

overpassing the bed while the heavy mineral is selectively trapped. A high bed roughness gives large transport rate ratios for sand-size sediment and implies that large voids are very favorable sites for preferential accumulation of heavy minerals. Coarse gold is more likely to be trapped than fine gold, and gold, because of its greater density, is trapped to a much greater extent than magnetite. However, as bed roughness decreases the ability of the bed to selectively trap high density minerals shifts towards finer grain sizes. Thus, preferential enrichment of sand-sized, high-density minerals will continue as long as the surface half-voids remain empty, but will be reduced as infilling of voids decreases both bed roughness and the transport rate ratios.

Behaviour of fine, silt-size particles requires further consideration. Most of this sediment will overpass the bed as washload and therefore has no opportunity to develop heavy mineral enrichments. However, as shown by the very low transport rates in Figure 3, fine particles that do enter the bed are effectively immobilized whatever their density. In Einstein's bedload formula this outcome results from inclusion of a "hiding" factor whereby small particles are protected from stream flow by larger particles. In the beds of real streams, transport and infiltration of very fine particles into the smallest passages within the bed will very effectively shield them from re-entrainment. Thus, although the relative transport rates of Figure 4 suggest the possibility of differential accumulation of very fine heavies, the very low absolute transport rates of such particles argue against such enrichments actually developing.

Changes in concentrations of gold along a stream's longitudinal profile will reflect a balance between the anomaly dilution model and the effects of decreasing gradient on the processes that favour preferential deposition of heavy minerals. Stream sediment surveys are often the preferred method of geochemical reconnaissance in hilly or mountainous terrains. There are therefore likely to be large changes in stream gradient going from sample sites on first order, headwater streams, to the third or fourth order streams sampled at lower elevations.

Calculations indicate that as slope decreases to one or two per cent, the transport rate ratio for magnetite:quartz increases with the response being greatest in the medium to coarse sand fractions (Figure 5). Thus, as gradient decreases along the longitudinal profile, a region may be reached where conditions are particularly favorable to preferential accumulation of gold and other heavy minerals. Placer gold deposits, displaced considerable distances downstream from their source, are the best known manifestation of this phenomenon. This dispersion model - with gold concentrations increasing away from their bedrock source - is clearly very different to the dilution model of geochemical anomalies.

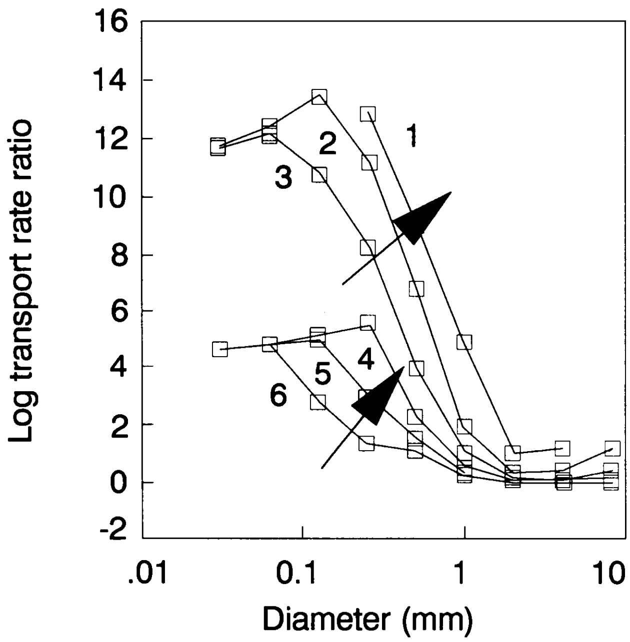

Figure 5. Effect of stream gradient on transport rate ratios for quartz:gold and quartz:magnetite. Curves (1), (2) and (3) for gold on slopes of 1%, 2% and 4%, respectively. Curves (4), (5) and (6) the corresponding plots for magnetite. Arrows indicate direction of decreasing slope. Hydraulic conditions as in Figure 3 and characteristic bed roughness (D_{65}) set at 4.0 mm. From Day and Fletcher (1990).

To summarize theoretical considerations, it is apparent that local (bed and bar) scale variations of gold concentrations in streams are very complex. Nevertheless, it seems likely that coarse gold will preferentially accumulate in areas of high bed roughness. In these locations accumulation (sorting) efficiency should decrease with decreasing size of gold particles. Entrainment (lag) deposits can develop on more uniformly sized, sandy beaches and overbank deposits could become enriched in "skim" gold. Changes in gradient along the stream's longitudinal profile might result in concentrations of gold increasing downstream, away from their bedrock source.

DESCRIPTION OF THE STUDY AREA

Harris Creek is a fourth order (scale 1:50 000) tributary of the Shuswap River in the southern interior of British Columbia (Figure 6). In the study area the upstream catchment has an area of approximately 220 square kilometres, of which about half lies above 1500 metres elevation on the Okanagan Plateau. Stream flow is strongly seasonal being dominated by floods from melting of the substantial snowpack that forms on the plateau. These floods cause stream discharge to increase from less than 1 cubic metre per second to peaks exceeding 10 cubic metres per second in early summer (Plates 1 and 2).

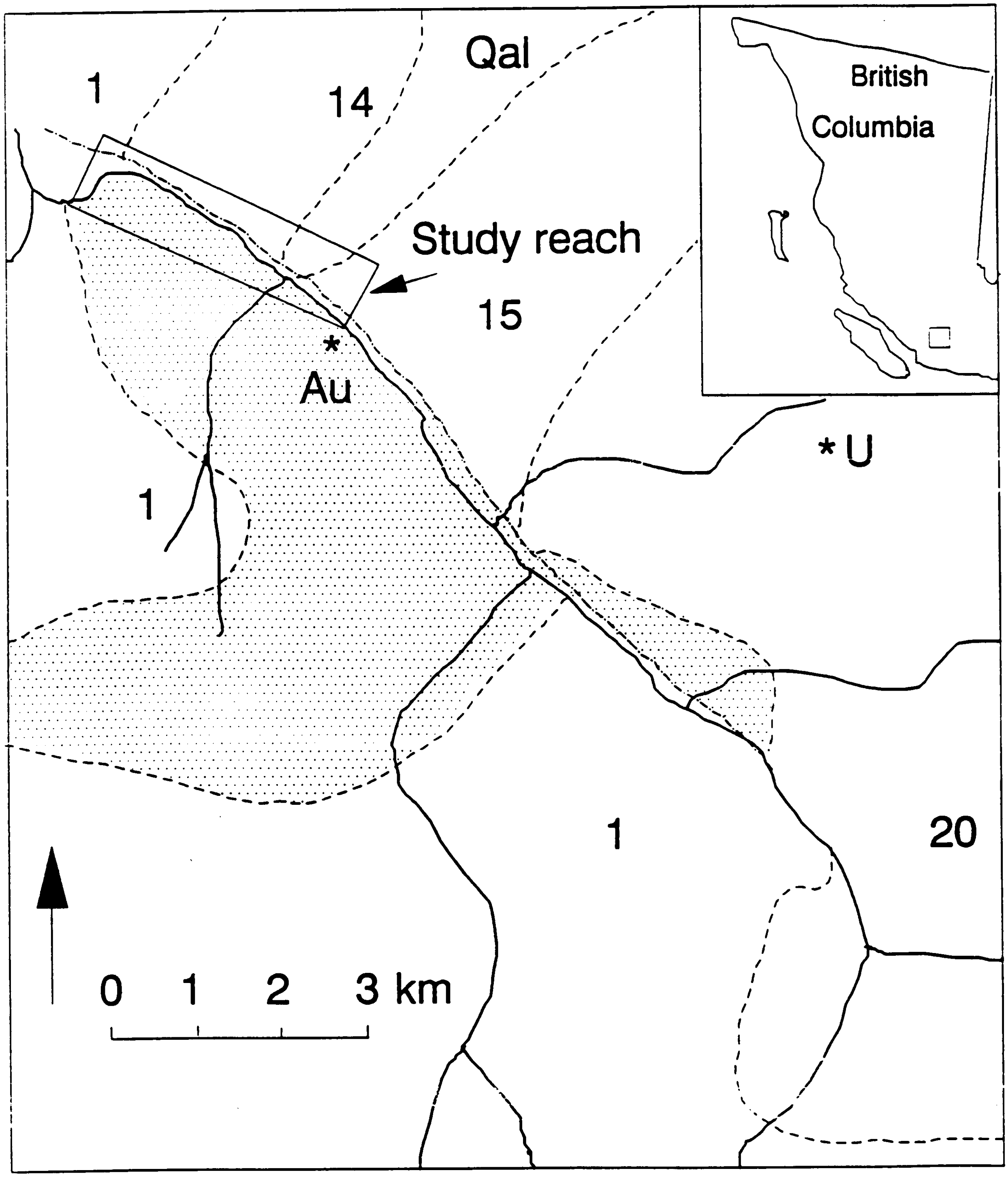

Figure 6. Location and simplified geology of the Harris Creek catchment. 1 = gneiss; 14,15 = andesite; 18 = granodiorite; 20 = basalt; Qal = alluvium, colluvium; * = minor mineral occurrences. Based on Day and Fletcher (1989).

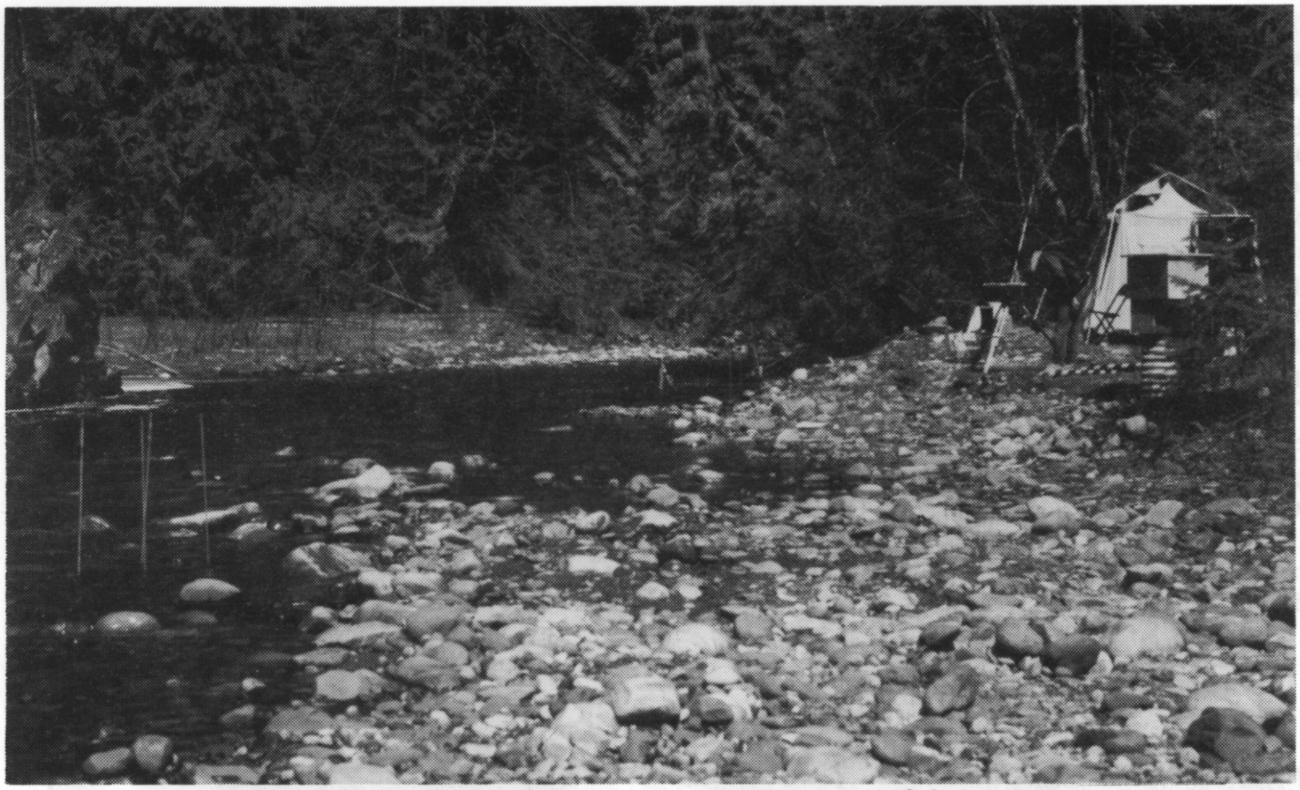

Plate 1. Head of bar, site M, Harris Creek: low discharge conditions 1 m^3s^{-1}, April 17, 1988.

Plate 2. Head of bar, site M, Harris Creek: flood conditions with discharge of 15 m^3s^{-1} on May 13, 1988.

The Okanagan Plateau is a rolling upland underlain by gneisses and plateau basalts concealed beneath a thin veneer of glacial till. At lower elevations the stream flows along a southeast-trending regional lineament bounded to the north by recessive andesite and to the south by granodiorites. A bedrock source for the gold in Harris Creek has not been found. However, small quartz veins in the gneisses and uraniferous fluvial channels beneath the plateau basalts are possibilities. Rich placer gold deposits were intermittently worked on Harris Creek, a short distance downstream of the study reach, in the late nineteenth and early twentieth centuries (Barlee, 1970).

The 5 kilometre study reach can be divided into upper and lower meandering sections with gradients of roughly 2 per cent, and a steeper (4%) braided midsection (Figure 7). Point bars, armoured by cobble-gravels, are well developed on the lower meandering section in a characteristic sequence of alternating riffles (*i.e.*, bar-heads) and bar-tail pools.

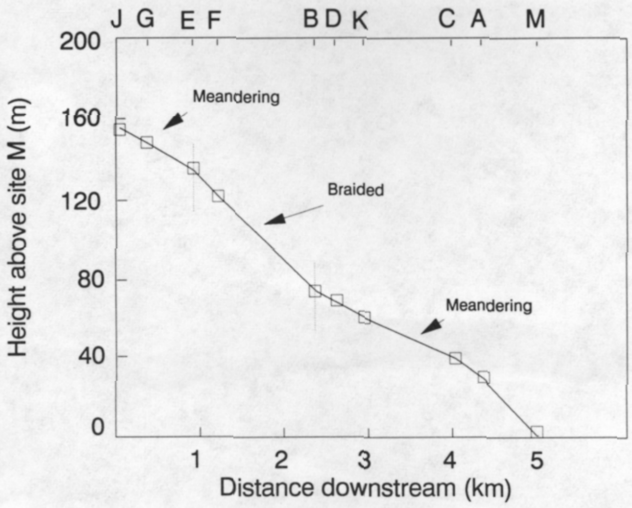

Figure 7. Longitudinal channel profile and sample locations along the study reach, Harris Creek. After Day and Fletcher (1989).

Plate 3. Pit traps in bar-head, site M, Harris Creek. Note the cobble armour.

METHODOLOGY

Ten sites (Figure 7) were sampled in June 1986, less than five days after the peak flood. At each site two samples were collected: one from cobble-gravels near the bar-head and the second from sandy deposits in the bar-tail eddy pool. Based on the results described in Section 1, sufficient material was processed to provide 60 kilograms of -2 millimetre sediment by wet-sieving into two 20-litre plastic pails. Some characteristics of the samples are summarized in Table 5 (Plate 3).

In the laboratory, samples were dried and wet sieved to yield eight size fractions. A hand magnet was then used to separate magnetic minerals from the -40+70, -70+100 and -100+140 mesh fractions. For the minus -140+200 and -200+270 mesh fractions a heavy mineral fraction was first separated using methylene iodide. This was then divided into its magnetic and non-magnetic constituents with a hand magnet. For the -270 mesh fraction a magnetic fraction was separated by suspending the sample in water and collecting the magnetic minerals on a magnetic stirring bar. All fractions were weighed. Gold content of the non-magnetic heavy mineral concentrates and the -270 mesh fraction was then determined by nondestructive instrumental neutron activation. Unless otherwise noted, analytical data for gold in heavy mineral concentrates have been calculated back to concentrations in the original sediment size fraction.

TABLE 5. PHYSICAL AND SAMPLING CHARACTERISTICS OF SEDIMENTS AT HIGH AND LOW-ENERGY SAMPLING SITES. BASED ON DAY AND FLETCHER (1989).

Sediment type	Characteristics
Low energy	
Unscoured, moderately to poorly sorted sands	Rippled sands in deep eddy pools at bar-tails. ATWS: 60 kg TTS: 30-45 minutes
Scoured, moderately to poorly sorted sands	Subaerial sand deposits at bar-tails. Visible magnetite accumulations where waves lap onto beach face and streamlets flow across sand. ATWS: 60 kg TTS: 30-45 minutes
High energy	
Very poorly sorted, bimodal, cobble-gravels	Sediment comprising most of bars. Cobble-gravel pavement. No visible layering. ATWS: 250 kg TTS: 2-3 hours

ATWS = Average total weight of field material processed to obtain 60 kg -10 mesh sediment
TTS = Typical time to process bed material in field and obtain 60 kg -10 mesh sediment

RESULTS

The principal objective of this part of the study was to check for local, systematic variations in gold content of the stream bed, particularly between bar-head and bar-tail sites. Results (Figure 8; Table 6) show that gold content of bar-head sites is typically in the range of 100 to 1000 ppb and is generally much greater than at the associated bar-tail site. Furthermore, because concentrations of gold at bar-heads remain roughly constant or even increase slightly through the reach, the difference between bar-head and bar-tail sites tends to increase downstream. Confidence limits (95%) between paired results overlap in only a few cases and show that the differences are generally statistically significant (Figure 9). Exceptions to the general trend and overlapping confidence limits are caused by the high gold values associated with the heavy mineral lag deposits found on the wave-washed beaches at several bar-tail sites. This is most noticeable at Site D.

Gold concentrations in -270 mesh sediment vary from less than 10 to a maximum of nearly 100 ppb. In this fraction there is only a very weak trend for bar-heads to be relatively enriched in gold.

Between size fraction trends, and the influence of hydraulic effects on gold accumulation, can be conveniently expressed as the geometric mean concentration ratios - GMCRs (Saxby and Fletcher, 1986) for the reach. These decrease from a value of 18.4 in the -140+200 mesh fraction to 2.1 for the -270 mesh fraction (Table 7) - a value of 1.0 would indicate that, on average, there was no systematic difference in gold values between high and low-energy sites.

Distribution of magnetite is very similar to gold, in that bar-head sites contain significantly greater concentrations than bar-tails (Figure 10 and Figure 11). Magnetite is also enriched in the visible heavy mineral lag deposits on wave washed beaches, *e.g.*, at Site D. However, as shown by the GMCRs, enrichment of magnetite is much weaker than for gold. Furthermore, whereas gold concentrations at bar-head sites remain roughly constant along the reach, magnetite concentrations tend to increase at bar-heads while remaining more constant at bar-tails (except where lags have formed).

TABLE 6. CONCENTRATIONS OF GOLD AND MAGNETITE IN HEAVY MINERAL CONCENTRATES AND SEDIMENTS ALONG THE STUDY REACH. BASED ON DAY AND FLETCHER (1989).

Fraction (ASTM)	Type[1]	Gravels (n=10) Mean	(CV)	Sands Unscoured (n=6) Mean	(CV)	Sands Scoured (n=4) Mean	(CV)
Gold (ppb)							
-140+200	HMC	4500	(10)	110	(27)	1500	(18)
-200+270	HMC	4400	(12)	260	(36)	2100	(14)
-270	SED	20	(33)	6	(33)	9	(38)
Magnetite (%)							
-40+70	SED	3.7	(70)	0.6	(34)	1.2	(50)
-70+100	SED	10.2	(57)	1.6	(21)	4.9	(40)
-100+140	SED	9.8	(50)	2.3	(26)	6.7	(29)
-140+200	SED	7.2	(59)	2.7	(22)	6.0	(24)
-200+270	SED	3.9	(42)	2.5	(35)	4.3	(27)
-270	SED	1.5	(67)	0.9	(48)	1.9	(77)

[1]Type: HMC = Heavy mineral concentrate; SED = Sediment
Mean = geometric mean for gold; arithmetic mean for magnetite; CV = coefficient of variation

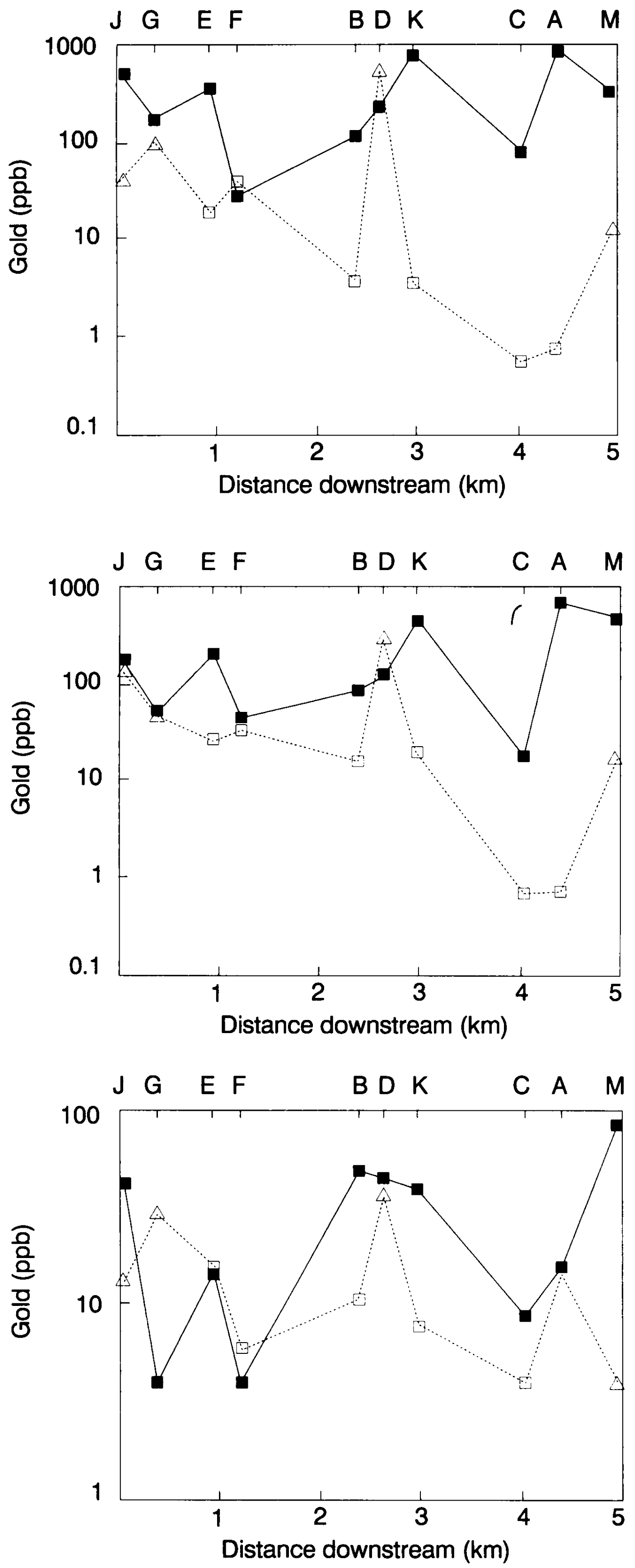

Figure 8. Distribution of gold along the study reach, Harris Creek: solid line = bar-head sites; dashed line = bar-pool sites with triangles and open boxes indicating lag deposits and pool sediments, respectively; (8a) -140+200 mesh; (8b) -200+270 mesh; (8c) -270 mesh. Based on Day and Fletcher (1990).

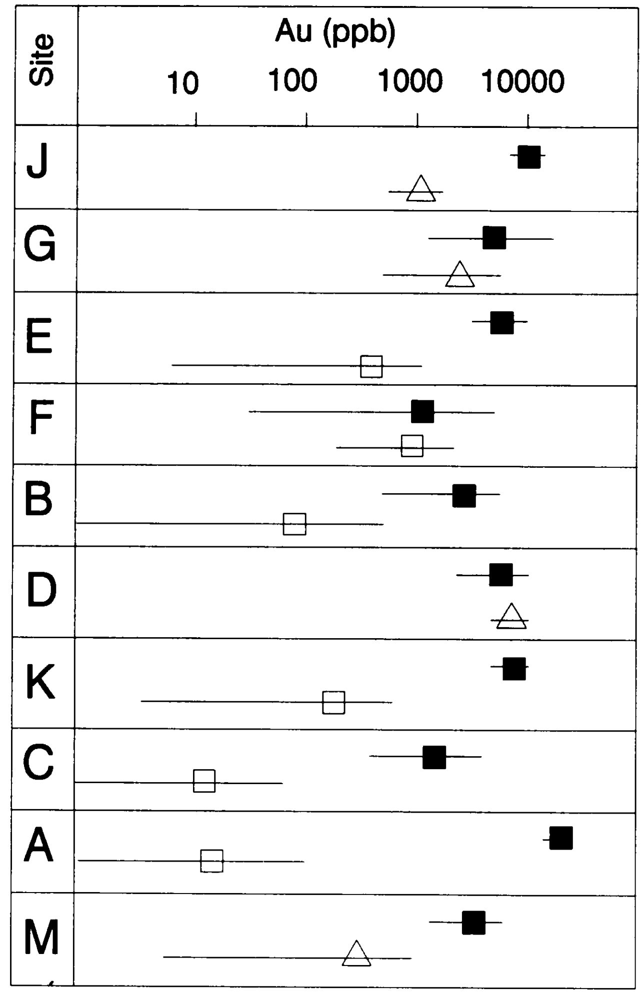

Figure 9. Gold concentrations of -140+200 mesh heavy mineral concentrates with 95% confidence limits based on Poisson distribution errors. Solid boxes = bar-head deposits; open boxes = bar-tail pools; and triangles bar-tail lag deposits. Based on Day and Fletcher (1989).

TABLE 7. GEOMETRIC MEAN CONCENTRATION RATIOS FOR GOLD AND MAGNETITE IN HARRIS CREEK. BASED ON DAY AND FLETCHER (1989).

Mineral	Fraction (ASTM)					
	-40 +70	-70 +100	-100 +140	-140 +200	-200 +270	-270
Gold	-	-	-	18.4	7.6	2.1
Magnetite	4.3	3.6	2.4	1.7	1.2	1.2

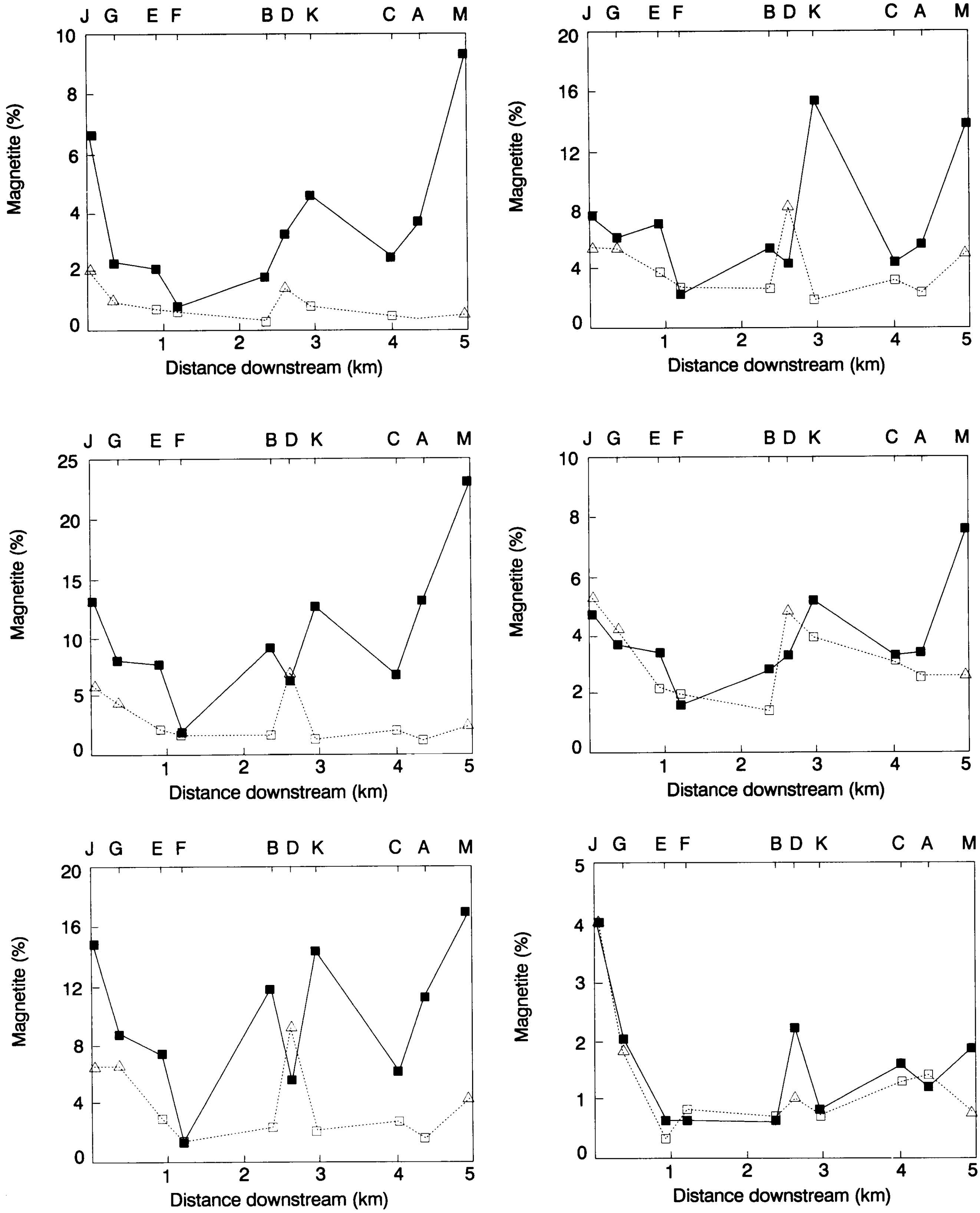

Figure 10. Distribution of magnetite along the study reach, Harris Creek: solid line = bar-head sites; dashed line = bar-pool sites with triangles and open boxes indicating lag deposits and pool sediments, respectively; (10a) -40+70 mesh; (10b) -70+100 mesh; (10c) -100+140 mesh; (10d) -140+200 mesh; (10e) -200+270 mesh; (10f) -270 mesh.

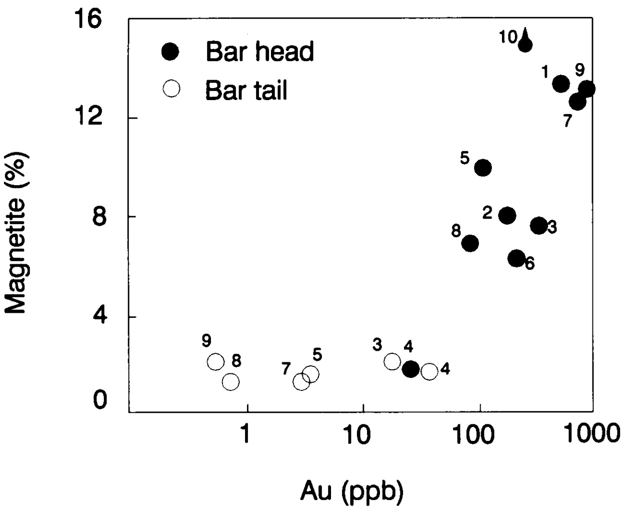

Figure 11. Concentration of gold in -140+200 mesh sediments versus magnetite in -70+100 sediments along the study reach, Harris Creek. Solid circles = bar-head deposits; open circles = bar-tail sandy pools sediments. Lag deposits not shown. Numbers increase going downstream, i.e., "10" corresponds to Site M. Based on Day and Fletcher (1990).

DISCUSSION

The following model attempts to relate the field observations to the theoretical behaviour of heavy minerals in streams.

Sediments, including coarse cobble-size clasts, are annually reworked and transported during the nival flood. For example, in the 1989 flood, cobbles with diameters greater than 64 millimetres were transported once discharge exceeded roughly 9 cubic metres per second. When the flood peak passes, this very coarse bedload stops moving. Voids between the clasts then provide openings in which finer sediment is deposited as discharge continues to fall. As already described, the high bed roughness of the cobbles will provide a natural riffle for accumulation of heavy minerals through repeated selective deposition and re-entrainment. Bar-heads are characterized by high bed roughness and can thus act as barriers to heavy minerals being transported downstream. For a given size range, the greater density of gold will result in it being much more strongly enriched than magnetite. Similarly coarse gold will be more efficiently trapped than fine gold - as shown by the GMCRs. Particles of magnetite and gold fine enough to be transported principally in suspension (rather than as bedload) will be swept over bars without contacting the bed but may then be deposited in back eddies or under lower flow velocity regimes in bar-tail pools.

In going from the bar scale to the longitudinal profile the effects of mineral supply and changes in stream gradient must be considered. Gold is assumed to be derived from an upstream point source or sources, whereas magnetite is added to the channel more or less continually, throughout the reach, by bank erosion. In the case of Harris Creek, trapping of gold in bar-heads is sufficient to offset any downstream dilution at these sites (*i.e.*, the anomaly dilution curve does not apply). For magnetite, which is being continuously supplied to the channel, its accumulation at bar-heads results in a downstream increase in magnetite concentrations. These increases are most noticeable downstream of Site B, where decreasing stream gradients (Figure 7) should further favour accumulation of heavies as proposed in Figure 5. In contrast to bar-heads, preferential accumulation of magnetite and gold is not an effective process in the sandy sediments of bar-tail pools. The gold anomalies at these sites therefore decay through the reach by downstream dilution whereas concentrations of magnetite show little variation.

SEASONAL VARIATIONS OF GOLD CONCENTRATIONS

INTRODUCTION

The model proposed in the previous section suggests that the efficiency with which gold is trapped at bar-head sites might vary with changing flow conditions. Furthermore, gold trapped in the voids of the cobble-gravel pavement might subsequently be buried by deposition of gold-poor sediment. The resulting seasonal or annual changes in gold concentrations would create serious problems in the organization and interpretation of exploration surveys. Therefore, from 1986 on, experiments were undertaken to evaluate these possibilities.

The first experiments, from 1986-1987, simply involved sampling adjoining 1 square metre areas of the bar-head on five occasions (Fletcher and Day, 1988a). Gold content of the heavy mineral concentrates was then determined by fire assay - atomic absorption spectroscopy. Results (Figure 12) showed a dramatic decrease from strongly anomalous gold values immediately after the 1986 flood, during which discharge exceeded 10 cubic metres per second for twenty-three days, to near-background values several months later. There was then a much smaller fluctuation associated with the relatively small 1987 flood event. These results amply confirmed the possibility of there being severe seasonal and annual variations in gold content of bar-head gravels. On this basis, more detailed studies of effects of changing discharge on heavy mineral transport and deposition started were started in 1988. These studies are still underway and only preliminary results will be described.

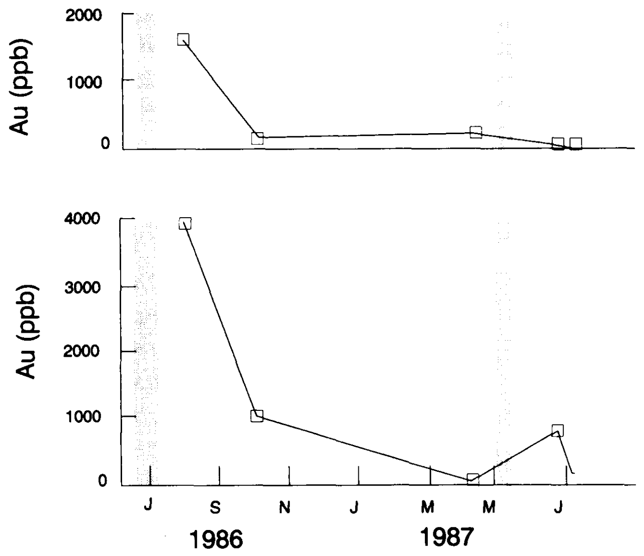

Figure 12. Seasonal variations of gold in -140+200 (upper figure) and -200+270 mesh (lower figure) heavy mineral concentrates from the bar-head at Site M. Shaded periods (19 June-11 July, 1986, and 30 April-2 May and 7 May-10 May, 1987) when stream discharge exceeded 10 m^3s^{-1}. From Fletcher and Day (1988a).

METHODOLOGY

Pit-type sediment traps were installed at the head, midsection and tail of the bar at Site M (Figure 13 and Plate 3). Each trap consisted of a length of 30-centimetre diameter concrete water pipe installed vertically in the bar with its upper rim level with the bar surface. A removable plastic pail (20 litres) was placed in each trap and covered with a 1 square centimetre screen lid. In this

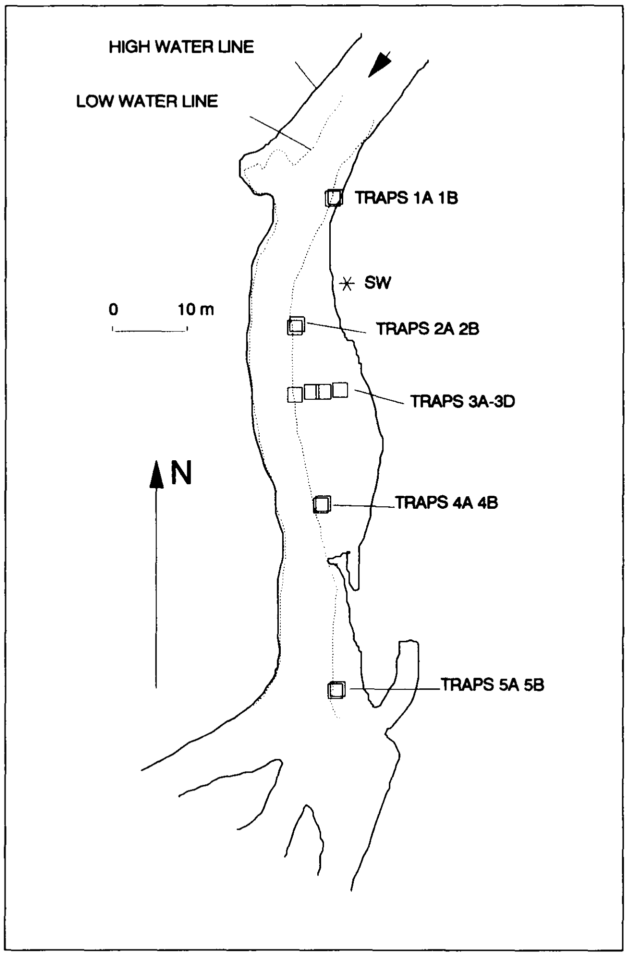

Figure 13. Channel morphology and locations of pit-traps on bar at Site M, Harris Creek. SW = stilling well.

configuration the traps should catch sediment, principally bedload, testing the bed as it is transported across the bar. Sediment was removed from the traps at irregular intervals as they filled. The data thus consist of roughly equal increments of sediment load that represent time intervals of hours to days to weeks depending on discharge conditions. Traps were operated between April 18 and June 17, 1988, and then again between April 2 and July 18, 1989. Stream discharge was measured continually over the same periods.

In the laboratory, sediments were wet sieved to give eight size fractions ranging from -270 to +10 mesh, with an upper limit of 1 square centimetre being imposed by the screen lids of the traps. Each fraction was dried and weighed. The magnetic fraction was then separated from the five size fractions between 70 and 270 mesh using a hand magnet. A nonmagnetic -100+270 mesh heavy mineral concentrate (SG >3.3) was prepared for determination of gold by fire assay - atomic absorption.

RESULTS AND DISCUSSION

The capacity of Harris Creek to transport sediment is strongly influenced by discharge. For example, the increase in average discharge from 4.28 cubic metres per second, prior to the flood peak, to a maximum of 19.57 cubic metres per second (interval average 17.39 m^3s^{-1}) on May 14, 1988 increased the rate of sediment accumulation at the bar-tail (Trap 5) from less than 10 grams to a maximum of 1880 grams per hour. Thereafter, rates of sediment accumulation decreased with minor pulses corresponding to fluctuations in discharge. Similar relationships were observed in the mid-bar and bar-head traps and there is a general consistency in trap behaviour (Church *et al.*, 1990). It should be noted that in both study years low snowpacks on the Okanagan Plateau resulted in relatively weak snowmelt floods with discharges exceeding 10 cubic metres per second for only three days in 1988 and five days in 1989 (Tables 8 and 9).

Magnetite concentrations in trapped sediments are typically close to 10 per cent. However, from May 12 to 14, 1988 concentrations increased to a maximum of nearly 20 per cent as discharge reached its peak (Figure 14). Over the same interval gold concentrations in the nonmagnetic heavy mineral concentrates increased very abruptly from less than 15 ppb to 1115 ppb on May 13 and 14 (Table 8). Thereafter, concentrations of both gold and magnetite fell to their normal values. Very similar trends are apparent in the corresponding data for 1989 (Figure 15 and Table 9).

Results show that: (i) the fivefold increase in discharge resulting from the snowmelt flood causes a roughly three order of magnitude increase in transport of -10 mesh sediment by Harris Creek; and (ii) gold and magnetite content of the transported sediments is also related to stream discharge with anomalous concentrations of gold only being transported during periods of high discharge.

As shown in Section 3.0, gold and magnetite are preferentially stored in bar-head gravels. The increased concentrations of magnetite and abrupt appearance of gold at the bar-tail during peak-flow conditions might therefore result from release of heavy minerals from the bed when stream velocities (and hence shear stresses at the bed) become sufficient to disrupt and move the cobble armour at bar-head sites. Movement of larger clasts and deeper scouring of the bed could account for the strongly anomalous gold concentrations found after the above-average snowmelt flood in 1986.

Whatever the reason, the increased concentrations of magnetite and gold in sediments transported during

TABLE 8. AVERAGE DISCHARGE VERSUS RATE OF SEDIMENT ACCUMULATION AND CONCENTRATIONS OF GOLD AND MAGNETITE, APRIL 18 TO JUNE 17, 1988. BASED ON FLETCHER AND WOLCOTT (1989).

Date	Discharge (m^3/sec)	Rate (g/hour)	Magnetite (%)	Gold (ppb)
April 18 - May 5	4.16	1.69	7.33	<15
May 5-12	5.61	58.59	8.90	<5
May 12	9.64	905.13	13.60	<10
May 12-13	15.84	346.19	14.46	10
May 13-14	17.39	1298.22	17.14	1115
May 15-17	8.79	157.49	11.81	15
May 17-22	5.92	15.17	8.42	60
May 22-23	7.45	213.61	11.30	<10
May 23-28	5.98	54.24	9.63	<10
May 28 - June 17	4.11	7.85	8.91	<5

Rate = total rate of accumulation -10 mesh sediment
Magnetite = weight per cent magnetite in -100+270 mesh heavies
Gold (ppb) = gold in -100+270 heavy mineral concentrate

TABLE 9. AVERAGE DISCHARGE VERSUS RATE OF SEDIMENT ACCUMULATION AND CONCENTRATIONS OF GOLD AND MAGNETITE, APRIL 2 TO JUNE 19, 1989.

Date	Discharge (m^3/sec)	Rate (g/hour)	Magnetite (%)	Gold (ppb)
April 2 - May 5	1.69	6.85	7.47	105
May 5-6	6.85	297.56	10.60	<20
May 6-7	8.41	670.55	11.63	<10
May 7	9.89	936.88	12.50	<20
May 7-8	12.12	1593.69	15.31	<25
May 8	10.04	969.22	12.29	465
May 8-9	10.38	1257.91	12.04	875
May 9-10	12.43	2442.40	12.16	1030
May 10-11	13.37	2537.72	12.51	450
May 11-12	9.32	330.72	10.15	2370
May 12 - June 19	5.13	27.56	8.36	100

Rate = total rate of accumulation -10 mesh sediment
Magnetite = weight percent magnetite in -100+270 mesh heavies
Gold (ppb) = gold in -100+270 heavy mineral concentrates

peak discharge have important implications for exploration geochemical surveys. In particular, gold content of "active" sediments is apparently very dependent on discharge conditions. Thus, in regions with large seasonal variations in stream flow, contrast for gold anomalies can vary seasonally and anomalies may even disappear if gold-rich sediments, deposited immediately after the flood peak, are subsequently buried by gold-poor sediments as discharge falls. This may explain the results shown in Figure 12. Sampling during or shortly after periods of high flow should therefore give the best anomaly contrast.

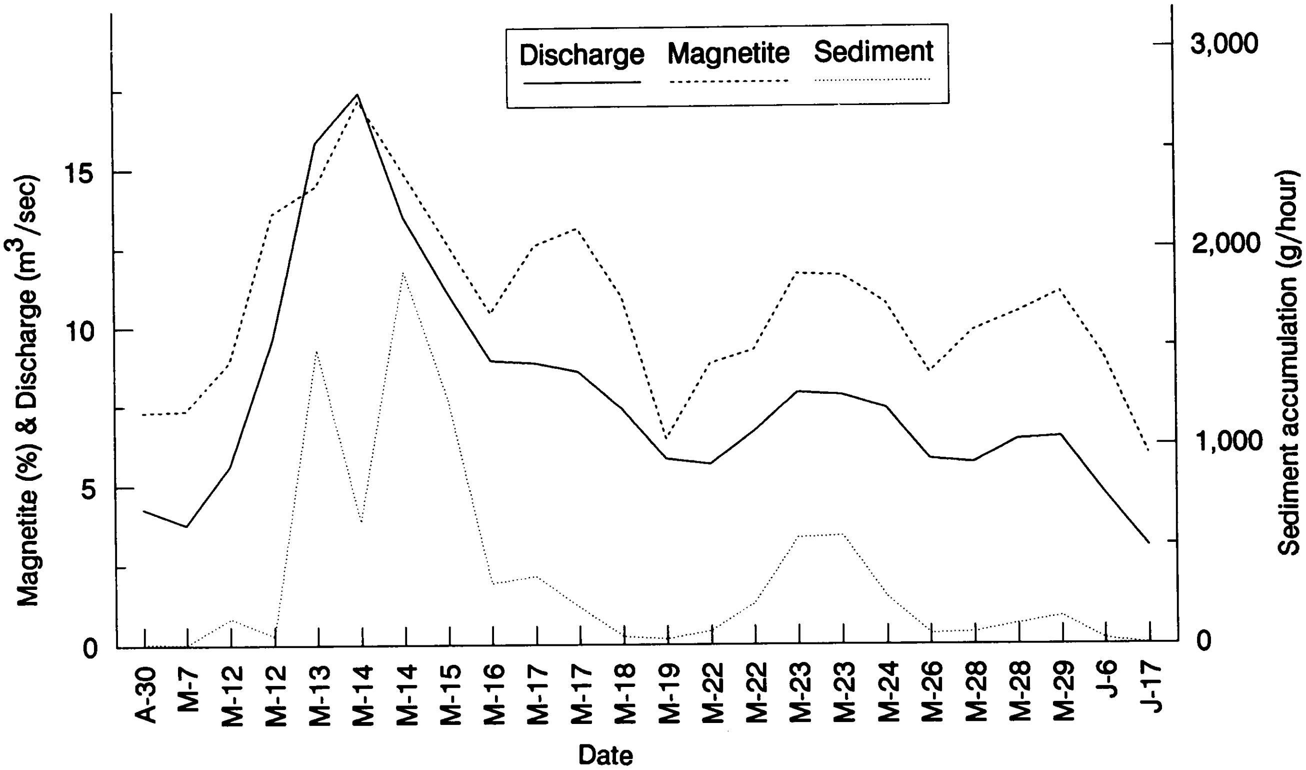

Figure 14. Variation in discharge, sediment accumulation rate and magnetite content of sediments, April 30 - June 17, 1988, at Trap 5 site of Figure 12.

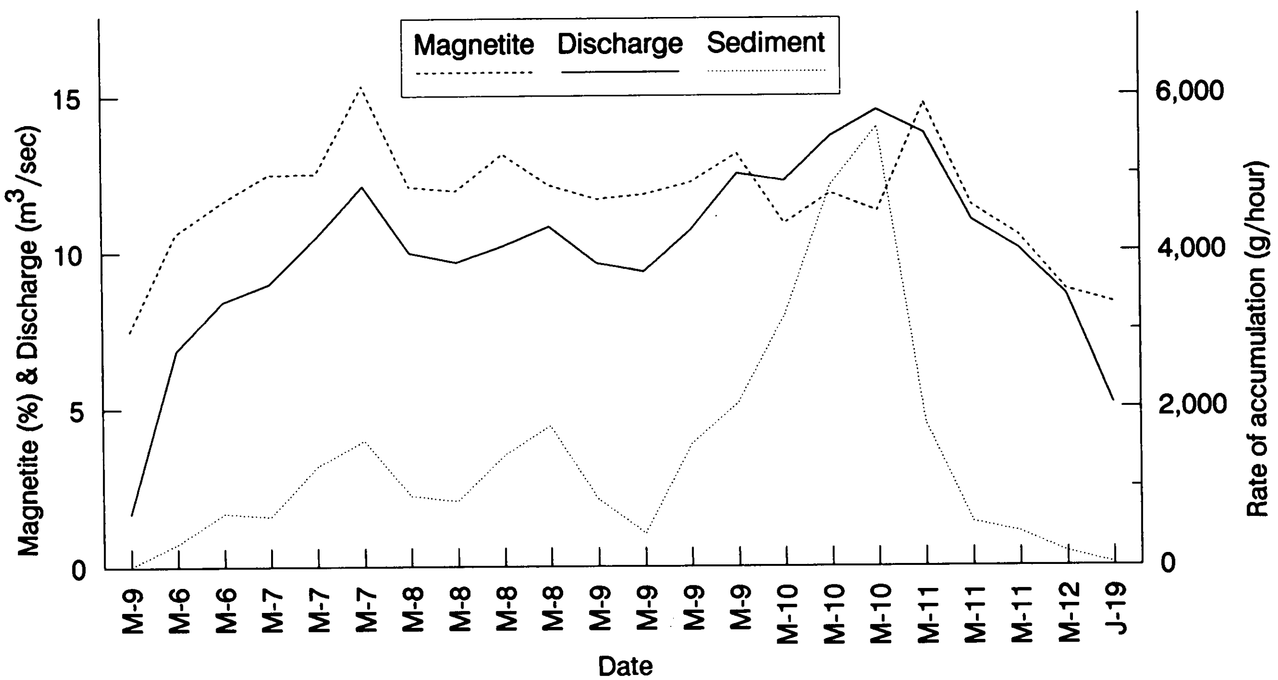

Figure 15. Variation in discharge, sediment accumulation rate and magnetite content of sediments, May 9 - June 19, 1989, at Trap 5 site of Figure 12.

IMPLICATIONS FOR EXPLORATION

Field data show that, as predicted by theoretical modelling, heavy minerals can become concentrated and segregated on the stream bed in response to bedform and hydraulic conditions. This can lead to considerable local variability in concentrations of gold on a stream bed (Figure 8). Furthermore, there can be equally large seasonal, and possibly longer term, variations in gold concentrations in response to changing discharge conditions (Figures 12, 14 and 15). These findings amply demonstrate reasons for the erratic character of gold anomalies in stream sediments and for their proclivity to "disappear" during follow-up surveys.

Clearly, although collection of statistically representative samples is essential, this alone is insufficient to provide meaningful, and hence interpretable, data on distribution of gold in stream sediments. To achieve this it is necessary to minimize local variability (both spatial and temporal) and, if possible, take advantage of the behaviour of the heavy minerals to optimize the various stages of a geochemical survey. These studies are therefore most usefully summarized as guidelines on **WHEN, WHERE and WHAT** to sample and analyze, and **HOW** to analyze samples and present the resulting data. Before doing so it must be cautioned that these guidelines are based largely on results for Harris Creek - a cobble-gravel bed stream with a strongly seasonal discharge from the annual snowmelt. Similar studies are needed for streams having different bed and discharge conditions.

WHEN TO SAMPLE

Evidence from Harris Creek suggests that in streams where flow conditions are strongly influenced by the early summer snowmelt, gold anomalies are most likely to be detected at bar-head sites early in the field season (Figures 12, 14 and 15; Tables 8 and 9). Samples should therefore be collected as soon as possible after the flood peak has passed.

The very strong gold anomalies found on Harris Creek in 1986 (Figure 12), a year with a much greater than average snowmelt flood, also suggest the possibility of longer term variations in gold concentrations. Such variations are obviously beyond the control of an exploration program, but should be considered when comparing results from different field seasons or in assessing the confidence to be placed on negative results.

WHERE TO SAMPLE

RECONNAISSANCE SURVEYS

Both the theoretical model and field data indicate that the greatest concentrations of gold and other heavy minerals should be found in cobble-gravels at high-energy, bar-head sites. Furthermore, because trapping of gold by bar-head gravels counteracts anomaly dilution, these anomalies persist (or even increase) downstream from their source (Figures 8 and 11). Sampling and analysis of heavy mineral concentrates from bar-head gravels should therefore give the best chance of a single sample establishing the presence or absence of a source of anomalous gold in a catchment provided that: (1) the anomaly has not been diluted or buried by gold-poor sediments deposited under low-flow conditions; and (2) the sample is sufficiently large to be representative.

The first limitation can probably only be overcome by digging as deeply as possible into the bed, thereby ensuring that gold-rich sediments deposited under high-flow conditions are sampled. Obtaining a representative sample is, however, difficult insofar as it requires the field processing and collection of very large amounts of sediment - typically several hundred kilograms of -4 mesh material or corresponding smaller amounts of finer sediment (Table 3). This can require two to three hours at each sample site (Table 5), but is essential if a representative +270 mesh heavy mineral concentrate is to be prepared for analysis. The time taken to collect such a large sample should, however, be at least partly offset by the large catchment area such a sample can reliably represent - approximately 200 square kilometres in the case of Harris Creek.

Failure to collect a representative sample results, on average, in underestimation of gold concentrations and in extreme cases will greatly increase the chances of missing an anomaly (Table 2). Consequently, it is probably best not to sample bar-head gravels if survey logistics preclude collection of adequate samples. Under these circumstances sandy sediments can be collected more quickly and easily from sandy pools at bar-tails (Table 5). However, anomalous dispersion trains will be shorter (Figures 8 and 11) and sampling density should be correspondingly increased. Erratic heavy mineral lag deposits produced by wave action on beaches should be avoided by sampling below the waterline.

FOLLOW-UP SURVEYS

In bar-head samples anomaly contrast can increase away from the bedrock source if changing stream gradients and bed roughness conditions become more favorable to trapping of heavy minerals (Figures 5, 8 and 11). Because there is no comparable mechanism for trapping of gold in bar-tail pools, the more easily collected sandy sediments from these sites should provide a better sense of direction (vector) to the source during follow-up surveys. Unless the -270 mesh fraction is used, a large sample is still required for preparation of a representative heavy mineral concentrate but sampling time is appreciably shorter than at bar-heads (Table 5). Lag deposits, with erratic gold values, should again be avoided by sampling well below the waterline.

WHAT AND HOW TO ANALYZE

The fundamental requirement is that the fraction chosen must contain gold derived from the bedrock gold mineralization that forms the exploration target. Beyond this minimum requirement, it is usually necessary to remove any barren dilutants so as to concentrate the gold into a representative subsample that is small enough (30 g or less) to be conveniently analyzed by fire assay - atomic absorption or instrumental neutron activation.

Conventionally these requirements are often met by concentrating the gold into a nonmagnetic heavy mineral concentrate. Size distribution of gold in this study suggests that dilution of gold by gold-poor fractions will be avoided by using the -100+270 or -140+270 mesh fractions to prepare a heavy mineral concentrate (Tables 1 and 2). Within these size ranges, GMCRs for gold indicate that variations in concentrations caused by hydraulic effects will be minimized by use of the finest size fractions (Table 7). However, results also emphasize the need to process very large samples if representative heavy mineral concentrates are to be obtained. This reflects both (1) the very small number of particles of +270 mesh gold in even anomalous samples (Table 2); and (2) the losses of fine gold involved in the preparation of a heavy mineral concentrate (*e.g.*, Wang and Poling, 1983; Giusti, 1986).

A possible alternative to preparation of a heavy mineral concentrate is direct analysis of the -270 mesh fraction which, in many cases, is estimated to contain an adequate number of particles of gold in a 30 gram subsample (Table 2). However, anomaly contrast in this fraction is inevitably much lower than in heavy mineral concentrates because of dilution of gold by the light minerals present. As a result, at several bar-tail sites on Harris Creek anomalous gold values in -270 mesh sediment are at or below typical analytical detection limits of 5-10 ppb gold. Lower detection limits can be obtained by extraction of gold with cyanide from 100 grams or larger samples (Fletcher and Horsky, 1988). However, before this approach can be recommended for routine surveys, further work is needed to establish response of different sample types to cyanidation and to determine background concentrations of cyanide-extractable gold.

A further aspect of the size distribution of gold is that, provided samples consist mainly of -270 mesh sediment and 30 grams or more were to be analyzed, any size fraction might give reasonably acceptable, though not optimum, results. Anomalous dispersion trains would probably be short, because very fine gold is not preferentially trapped at bar-heads, and erratic because of the sporadic presence of flakes of coarse gold. In this context it should be noted that cyanidation of bulk samples (1 kg), with minimal sample preparation, is already routinely used in Australia (Elliott and Towsey, 1989).

DATA PRESENTATION

Analytical results for gold in heavy mineral concentrates are usually expressed as either: (1) relative concentrations (ppm or ppb) in the concentrate, or (2) if weights of sediment fractions are available, calculated back to the concentration in the original sediment. Because heavy minerals behave similarly and accumulate together on the stream bed, the first method of presentation will minimize variability caused by hydraulic effects but will increase variations resulting from differences in heavy mineral supply.

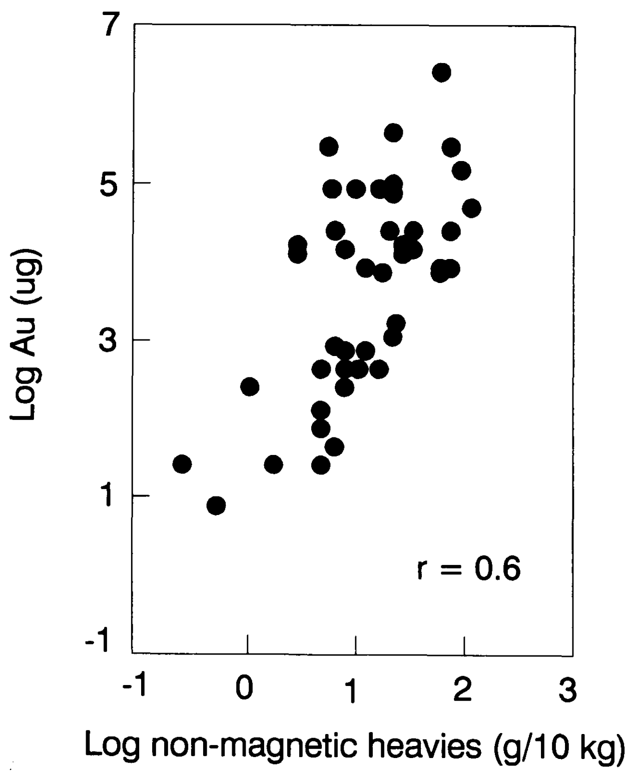

Figure 16. Gold content nonmagnetic heavies versus weight of nonmagnetic heavies in stream sediments from Nevada. Based on Fletcher and Day (1988b, 1989).

In order to minimize variations in gold concentrations resulting from either hydraulic effects or variable supply of heavy minerals, data can be normalized against another variable. There are two basic approaches (Fletcher and Day, 1988b; 1989): (1) ratioing gold concentrations to those of another heavy mineral or fraction that behaves hydraulically similarly, or (2) calculating an absolute abundance of gold (*i.e.*, relative abundance x fraction weight). Ideally the first method would minimize the effects of hydraulic variability between sites whereas the second would eliminate differences resulting from downstream dilution or variable supply of heavy minerals from different geological units.

Misapplication of either method of normalizing the data will actually increase unwanted noise. For example, in Figure 8, the abnormal gold enrichments in the bar-tail lag deposit at Site D can easily be recognized and corrected for by ratioing them to the high magnetite values at the same site (Figure 10). Conversely, multiplying the gold values at Site D by abundance of either magnetite or heavy mineral concentrations would only exaggerate the influence of heavy mineral lag deposits as a source of unwanted noise. Choice of the most appropriate method of data presentation is therefore dependent on the source of the variability to be minimized. A scatterplot can be a useful interpretive guide. For example, Figure 16 shows a fivefold increase in abundance of gold for a threefold increase in abundance of nonmagnetic heavy minerals. In this case hydraulic (*i.e.*, concentration rather than dilution) effects are clearly a major source of variability and the data are probably best presented as concentrations of gold in the heavy mineral concentrate. Such plots also enable the quality of sampling to be evaluated: ideally consistent sampling of the same bedform throughout a survey area would give similar yields of heavy minerals at each site and thus a narrow range on the abscissa of Figure 16.

CONCLUSIONS

- The distribution of gold in sediments from a cobble-gravel bed stream in southern British Columbia is consistent with a theoretical model of sediment transport based on Einstein's bedload transport formula.
- Both theory and the field observations suggest that heavy mineral concentrates from bar-head gravels provide the most reliable sample sites for detecting the presence of gold in low-density reconnaissance surveys. Samples are best collected immediately after peak-discharge events and large amounts of material (up to 250 kg) must be processed in the field to obtain a representative sample for preparation of a -100 or -140 mesh heavy mineral concentrate. **Collection of bar-head samples that are too small to be representative can seriously compromise the reliability of a survey.** Therefore, if it is not practical to collect adequate samples at these sites, sandy sediments from bar-tail pools should be considered as an alternative: less material must be processed in the field but higher sampling densities are required because of shorter anomalous dispersion trains. This is also probably the most suitable approach for follow-up surveys. Erratic heavy mineral lag deposits on beaches are probably best avoided.
- In many cases, it should be possible to avoid preparation of a heavy mineral concentrate and the need to process very large samples by direct analysis of the -270 mesh fraction. This also reduces hydraulic effects and thereby makes selection of sampling sites less critical. However, even in a strongly anomalous stream such as Harris Creek, anomaly contrast is greatly reduced and concentrations of gold can fall below the detection limits (5-10 ppb) of conventional analytical methods. Extraction of gold from large samples (100 g or more) by cyanidation gives much lower detection limits but requires more investigation before it can be recommended for routine use.
- The optimum method of data presentation depends on whether the supply of heavy minerals to the streams or local hydraulic effects are the major source of unwanted variability in the gold results. Comparison of the distribution of gold to other heavy minerals (*e.g.*, magnetite) allows the quality of sampling and magnitude of hydraulic effects to be evaluated.

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